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WATER ECOSYSTEMS OF ARID TERRITORIES

The Hydrochemistry and Hydrobiology of Technogenic Reservoirs at Mining Territories of the Southeastern Transbaikal Region

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Abstract—Reservoirs of anthropogenic genesis are a special component of the technogenic landscape. Their environmental conditions differ from those of natural water bodies. Such differences include a limited catchment area and a low thickness of bottom sediments, as well as high contents of metals, metalloids, and salts. The objects of our research are various lake formations that formed during the development of mineral deposits in the Eastern Transbaikal region. This article describes the chemical composition of the waters and the species diversity and the structure of hydrobiont communities that are different in their formation and purpose of technogenic reservoirs of mining areas. Algae and zooplankton of technogenic water bodies in a region with an arid climate have been studied for the first time. The studied waters have a variety of morphometric and physicochemical characteristics with a wide range of pH values (2.99–8.80), total mineralization (85.9–9065 mg/L), and content of ore and associated elements. According to the chemical composition, the waters are sulphate and bicarbonate-sulphate, with different ratios of magnesium and calcium. The species diversity of the algae and zooplankton of the studied water bodies is low (75 taxa of plankton algae, 8 taxa of macroalgae, and 63 species and subspecies of plankton invertebrates). This is associated with extreme environmental conditions, where species richness is influenced by physicochemical conditions of the habitat. The determining factors for the development of Cryptophyta representatives are micro- and macrocomponent composition and general mineralization, for other groups of phytoplankton (Cyanobacteria, Bacillariophyta, Chrysophyta, Charophyta, Chlorophyta, Euglenophyta, and Dynophyta) it was the content of bicarbonates. Quantitative indicators of zooplankton are positively related to the concentration of ammonium nitrogen (for Crustacea) and negatively to pH (Rotifera).

Keywords: mining fields, technogenic reservoirs, hydrochemical composition, phytoplankton, macroalgae, zooplankton

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INTRODUCTION

The technogenic landscape is formed in processes of economic activity and radical restructuring of natural complexes. Artificial reservoirs of various types created and/or formed at mining sites (Grishchenko, 1999), known in the world literature as pit lakes and mining lakes (Bielańska-Grajner and Gładysz, 2010; Weithoff et al., 2010; Blanchette and Lund, 2016), are one of the components of such landscapes. Despite their wide distribution, the formation, functioning, and prospects for the existence of these newly formed natural-anthropogenic systems have not been sufficiently studied (Kumar et al., 2009; Goździejewska et al., 2021). This is especially true for the study of their hydrobiontic communities. However, there are some works dedicated to the biota of mining (quarry) lakes in Africa (El-Bassat and Taylor, 2007), Europe (Wollmann et al., 2000; Beulker et al., 2003; Nixdorf et al., 2003; Bielańska-Grajner and Gładysz, 2010; Weithoff et al., 2010; Moser and Weisse, 2011; Goździejewska et al., 2021), and America (Kalin et al., 2001; Ferrari et al., 2015). The study of water bodies of the mining areas is important for solving various environmental problems, such as development of hydrobiont communities in complex geochemical conditions and improvement of water quality for the purposes of multilateral human use (Kumar et al., 2009; Blanchette and Lund, 2016; Skrzypczak et al., 2020; Paulsson and Widerlund, 2021; Ramanchuk et al., 2021; She et al., 2021).

On the territory of the Transbaikal region, where the mining industry is one of the main sectors of the economy, technogenic water bodies remain poorly studied in terms of geochemical studies (Chechel and Zamana, 2009; Zamana and Chechel, 2015; Zamana et al., 2020; Chechel, 2020), and practically not studied in the hydrobiological aspect (Afonina and Afonin, 2015, 2017; Afonina and Itigilova, 2012; Kuklin, 2014). Comprehensive studies of the chemical and biological components of technogenic water bodies on the territory of the region were carried out for the first time. The purpose of this work was to study the chemical composition in various types of technogenic waters and the main characteristics of hydrobiont communities for an objective assessment of the ecological state of anthropogenic water bodies.

MATERIALS AND METHODS

Study Area

The studied mining objects of South-Eastern Transbaikal region, that is, the Sherlovaya Gora tin-polymetallic deposit, Spokoininsk tungsten deposit, Zhipkoshinsk antimony deposit, and Malokulindinsk and Orlovsk rare metal deposits, are located within the Onon-Argun steppe. The landscapes of the area are predominantly represented by a middle-mountain steppe with small areas of forest-steppe landscapes in the near-top part of the northern slopes. So, steppe and subtaiga landscapes are mixed in the area (Solodukhina and Pomazkova, 2014). Surface mining of deposits led to the development of technogenic landscapes on the adjacent territories. There are two types of terrain: open quarry-dumps and anthropogenic bottom-quarry lakes, fed by groundwater and precipitation.

The territory of the Sherlovaya Gora deposit is located within the granite massif of the same name, which is characterized by complex tin-polymetallic mineralization. The deposit was surface mining operated by the Sherlovaya Gora mining and processing plant (MPP) until 1995. Two ore fields are distinguished within the Orlovsk–Spokoininsk ore cluster: Orlovsk and Spokoininsk. The Orlovsk ore field includes the tantalum deposit of the same name. Extraction of tantalum ores at the Orlovsk deposit was carried out by an open method. The tailing dump of the Orlovsk MPP, into which tungsten and tantalum ore enrichment tailings were previously discharged, is filling with slurry from the processing of ores from the Spokoininsk deposit. The Spokoininsk deposit belongs to the greisen wolframite-cassiterite type. Surface mining is still ongoing. Prior to the launch of the Orlovsk MPP, the products of tungsten ore processing were dumped into the tailings. In the Malokulindinsk deposit, quartz-microcline and quartz-microcline-albite pegmatites are distinguished by their mineral composition. The deposit was open surface operated by the Orlovsk MPP until 1999. At the Zhipkoshinsk deposit two quarries produced sulfide-antimony concentrate from 2006 to 2018.

Field studies were carried out in June 2021 on the water bodies of the mining facilities of the Sherlovaya Gora (seven water bodies), Zhipkoshinsk, Orlovsk (two water bodies each), and Spokoininsk (one water body) deposits. In the area of the Malokulindinsk deposit, the waters of the Malaya Kulinda River (a tributary of the Onon River) were tested at two points as well as the pond formed by the river. A total of 14 water bodies were surveyed (Fig. 1).

The ore open pit of the Sherlovaya Gora deposit is the deepest (more than 35 m) and has the biggest area (0.143 km^2). The depth of the Orlovsk tailing dump ($S = 0.049$ km^2) in the central part was up to 3.6 m. The tailing dump of the Sherlovaya Gora deposit is the shallowest; its greatest depth did not exceed 0.5 m. The water surface area of other water bodies varied from less than 0.001 km^2 (a dammed lake, the Malaya Kulinda River and Zhipkoshinsk quarries) to 0.049 km^2 (a dammed lake near the Sherlovaya Gora settlement).

Collecting and Processing of the Samples

The collecting of hydrochemical and hydrobiological samples was carried out in the coastal area (depth up to 0.5 m), along the Sherlovaya Gora deposit and the Orlovsk tailing dump, and in the central (deep-water) part of the water bodies. The chemical analysis of waters was carried out in a certified laboratory of the Institute of Natural Resources, Ecology, and Cryology of the Siberian Branch of the Russian Academy of Sciences (Chita), the determination of anions, biogenic components, and permanganate oxidizability was carried out by conventional methods. The main cations and metals were determined by the atomic absorption method on a SOLAAR M6 spectrophotometer. As well, additional water samples were taken for subsequent analysis by the inductively coupled plasma mass spectrometry method (ICP-MS). Chemical analysis of water by the ICP-MS method was carried out at the Vinogradov Institute of Geochemistry of the Siberian Branch of the Russian Academy of Sciences (Irkutsk) on the ELEMENT2 device.

Collection and analysis of phytoplankton, zooplankton, and macroalgae samples was carried out using standard methods (Kiselev, 1969; *Vodorosli*, 1989; Sadchikov, 2003). Phytoplankton samples were taken from one to three horizons (surface, transparency depth, and bottom), zooplankton samples were taken totally (bottom-surface) with a Juday plankton net (sieve mesh size 0.064 mm) and filtering 100 L of water (integral sample) through the net (mesh size 0.073 mm). The species composition and quantitative characteristics (abundance and biomass) were determined. The biomass of algae was determined by the volume of individual cells or colonies of algae (Sadchikov, 2003), in zooplankters, by the equations of the relationship between body length and wet weight (Ruttner-Kolisko, 1977; Balushkina and Vinberg, 1979). The classification of taxa and synonyms for each group of algae are given according to the electronic database AlgaeBase (Guiry and Guiry, 2019); the name of zoo-

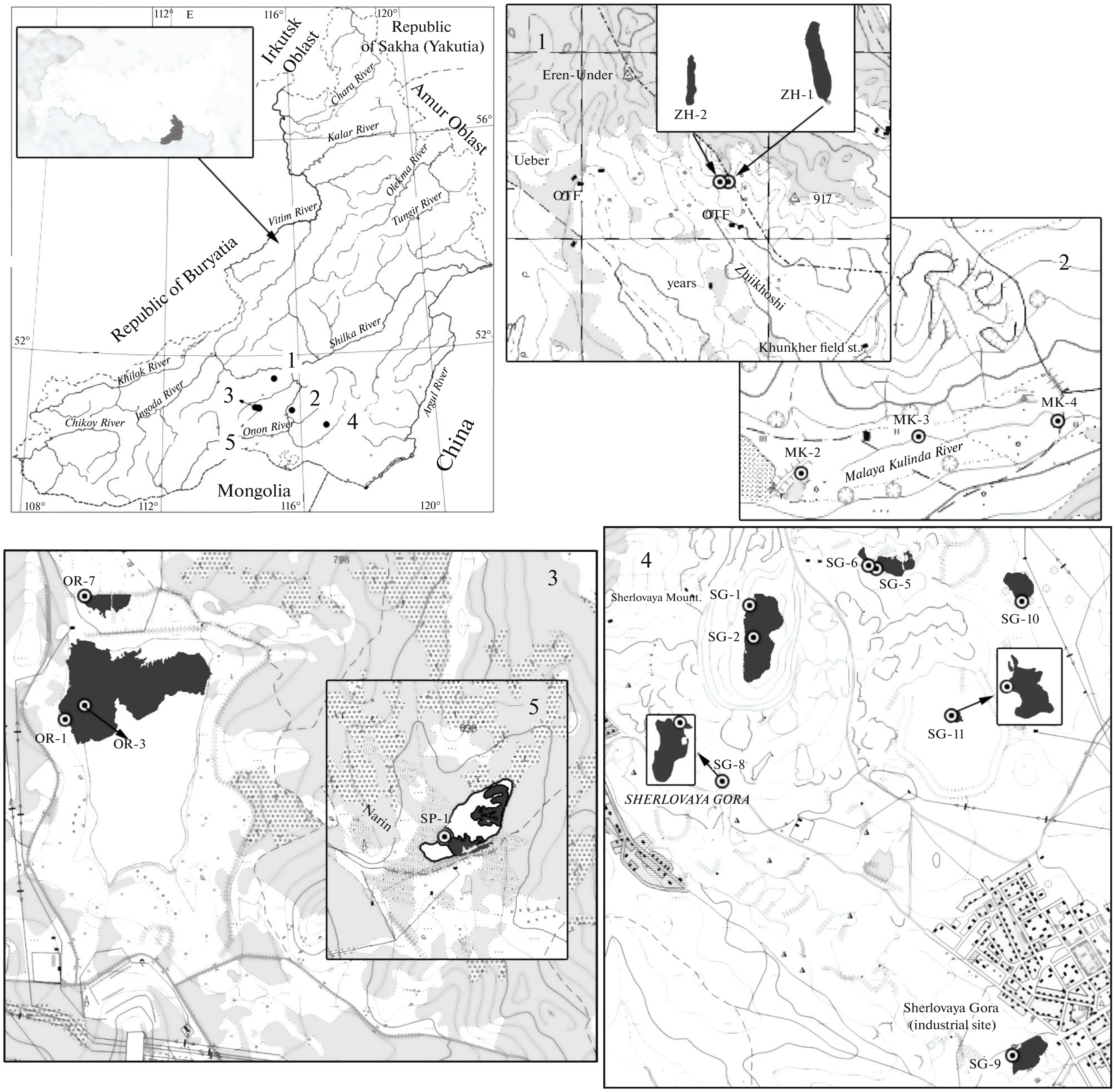

Fig. 1. The locations of sampling points of the studied technogenic water bodies of ore deposits: 1, Zhipkoshinsk deposit (ZH-1, ZH-2, mining lakes); 2, Malokulindinsk deposit (MK-2, a dammed lake; MK-3 and MK-4, Malaya Kulinda river); 3, Orlovsk deposit (OR-1, OR-3, tailing dumps, OR-7, lake downstream the tailing dump); 4, Sherlovaya Gora deposit (SG-1, SG-2, ore quarry; SG-5, SG-6, ponds; SG-8, lake downstream the dumps of the ore quarry; SG-9, dammed lake near the village of Sherlovaya Gora; SG-10, mining lake; SG-11, tailing dump); 5, Spokoininsk deposit (SP-1, tailing dump).

plankton species and taxa is given in accordance with modern nomenclature (WorMS, 2022). Simultaneously with sampling, water temperature and specific electrical conductivity were determined (using a multiparameter analyzer WTW Multi 340I (Germany)), as well as redox potential and pH (using an Anion 7051 water analyzer). The depth was measured with a lot; water transparency, by the white Secchi disc.

Data Analysis

Mathematical processing of the obtained data was carried out using the Microsoft Excel 2010 and STATISTICA 10 software packages. To study the relationship between the structural characteristics of plankton (the total number of phyto- and zooplankton species, the number of species in taxonomic groups (Cyanobacteria, Bacillariophyta, Cryptophyta, Chrysophyta, Charophyta, Chlorophyta, Euglenophyta, Dynophyta, Rotifera, Copepoda, and Cladocera), abundance and biomass of all phyto- and zooplankton and separate taxonomic groups) and abiotic environmental factors (water temperature, total mineralization, pH, Eh, macro- and microcomponent composition, permanganate oxidizability, and biogenic elements) we used principal component analysis (PCA). The data were normalized by dividing the initial data by the standard deviation of the corresponding variables (Shipunov et al., 2014). The absolute value of the load above 0.7 was taken as a significant relationship.

RESULTS AND DISCUSSION

The Physicochemical Characteristics of the Studied Water Bodies

The morphometric and physicochemical parameters of the studied water bodies differed significantly (Table 1).

The water temperature in the reservoirs varied from 11.6°C (Spokoininsk tailing dump and Zhipkoshinsk quarry) to 24°C (Sherlovaya Gora tailing dump). Water transparency in the deep-water ore open pit was 3 m, while in the Orlovsk tailing dump, it was 0.6 m.

The waters in the Sherlovaya Gora ore quarry are acidic (pH ranges from 2.99 to 3.14). Physicochemical parameters of the water composition varied with the depth increase. A temperature jump was recorded in the upper layer: the water temperature decreased from 15.7°C (at the surface) to 5°C (at the bottom). Eh values also decreased significantly (from 508 to 270 mV) as well as the concentration of dissolved oxygen (from 0.44 to 0 g/L). Mineralization increased from 3026 to 6210 mg/L (considering concentrations of Al and heavy metals) and concentrations of metals and SO_4^{2-}, Cl^-, F^-, and Mg^{2+} ions also increased. The pH value was typical for the strongly acidic environments, regardless of the depth of the water body. According to the chemical composition, the quarry waters are sulfate magnesium–calcium and zinc–magnesium–calcium (Table 1).

The waters of the Sherlovaya Gora tailing dump were also characterized by a low pH value (3.03). A significant increase in mineralization up to 9065 mg/L was noted due to the accumulation of SO_4^{2-}, cations, and metals. According to the chemical composition, the waters are sulfate calcium–magnesium (Table 1). Slightly acidic pH values (5.9 and 6.04) were determined in the waters of the ponds located near the ore quarry. Their mineralization varied from 2839 to 5191 mg/L. The chemical type of water is sulfate calcium–magnesium (Table 1).

A significant transformation of the physical and chemical parameters of groundwaters resulted from the technogenic disturbance of the geological environment during the development of the Sherlovaya Gora deposit, which resulted in the formation of strongly acidic and acidic sulfate waters. The waters of the ore quarry are characterized by vertical stratification of physicochemical parameters (thermo-, oxy-, chemocline), which was also observed in other acidic mining lakes of Bashkortostan, the Southern Urals (Udachin et al., 2008, 2009), Austria, Germany (Weithofa et al., 2010; Moser and Weisse, 2011), and Canada (Gammons et al., 2009).

The waters of the other studied water bodies were neutral and slightly alkaline (pH 6.04–8.29). The Eh values varied from 142 to 232 mV. Mineralization varied from 92 to 2249 mg/L. According to the chemical composition, the waters are predominantly sulphate with different ratios of magnesium and calcium (Table 1).

River waters of the Malaya Kulinda River are ultrafresh and fresh (85.9–108 mg/L) with neutral pH values (6.99–7.08) and a weak oxidizing (transitional) environment (184–191 mV). The chemical type of the waters is hydrocarbonate-sulfate magnesium-calcium.

The highest content of nitrogen (in the form of a nitrate ion) was detected in the waters of a dammed lake near the settlement Sherlovaya Gora. Probably, the source of this form of nitrogen is of a biogenic nature, while in the waters of the Orlovsk tailing dump, the source of NO_3^- is the residual nitrogen from explosives used for ore processing, as was shown for other deposits of the region (Zamana et al., 2020). The background content of inorganic nitrogen in the water of one of the Zhipkoshinsk quarries is slightly higher. However here it is in the ammonium form, the transition to which can be caused by a lower Eh value. The content of total phosphorus (when the content is above 0.1 mg/L, the organic form dominates) is increased in water samples from the Spokoininsk tailing dump and Zhipkoshinsky quarries. This can be explained by the enrichment of ores in phosphate minerals or the composition of the biota and biotic processes in these water bodies. The silicon content of the waters of the Sherlovaya Gora quarry and the tailing dump are outstanding, resulting from the high acidity of the environment, which enhances the leaching of silicate and aluminosilicate minerals and prevents the mobilization of silicon by secondary hydrogenous minerals.

Unfavorable conditions for the migration of heavy metals determine their relatively low contents in the waters of the tailings of the Orlovsk MPP and the lake located below its dam. Elevated concentrations in these waters were recorded only for manganese and iron. The Spokoininsk tailing dump was not exploited for a long time, and the waters of its pond were characterized by a low metal content. Relatively low concentrations of heavy metals in the waters draining the Malokulindinsk and Zhipkoshinsk deposits are associated with their geological structure, as well as by the unfavorable migration environment. At the same time, such highly toxic elements as arsenic and antimony

Table 1. The physicochemical parameters of technogenic waters of mining facilities of ore deposits in the Eastern Transbaikal region

Parameters*	Sampling Points											
	SG-1, 2	SG-5	SG-6	SG-8	SG-9	SG-10	SG-11	OR-1, 3	OR-7	SP-1	MK-2, 3, 4	ZH-1, 2
S, km^2	0.143	0.033	0.006	0.001	0.049	0.036	0.005	0.513	0.025	0.025	12**	0.001
T, °C	5–15.7***	18.2	21.6	18.1	17.6	15.5–16.6	24.0	14.8–17.6	13.0	11.6	13.8–15	11.6–12.0
pH	2.99–3.14	6.04	5.90	8.80	7.82	7.73	3.03	7.77–7.80	7.53	6.77	6.99–7.08	8.27–8.29
Eh, mV	270–508	265	261	181	170	145	295	142–172	174	190	184–191	211–232
PO, mg O/L	0.50–34.2	0.78	2.25	2.68	2.83	1.32	0.70	2.75–2.98	3.69	18.0	16.7–27.6	0.94
HCO_3^-, mg/L	0	0	0	73.3	211.7	172.6	0	166–167	238	47.1	40.6–45.7	49.3–72.1
SO_4^{2-}, mg/L	2076–3608	1993	3448	210.7	130.9	1496	5879	94.2–96.6	134	9.09	18.4–25.8	52.3–157.9
Ca^{2+}, mg/L	363.1–600	207.2	355.1	41.7	46.9	371.6	607	40.6–42.4	63.9	12.8	10.9–14.5	28.1–44.3
Mg^{2+}, mg/L	159.1–321	224.5	317	30.6	33.2	143.8	494	9.26–9.34	15.7	3.58	3.46–4.42	6.25–10.6
Na^+, mg/L	23.5–35.1	25	31.4	22.7	34.3	49.4	182.7	34.9–35.4	50.3	3.60	6.01–7.78	3.82–10.9
K^+, mg/L	4.37–12.1	3.65	6.73	0.39	1.60	4.17	19.1	15.5	7.77	9.89	2.34–5.95	1.3–1.77
NO_3^-, mg/L	0.62–1.78	5.13	7.77	1.03	19.6	0.82	1.88	9.82	2.25	0.78	1.18–1.71	1.80–2.64
NO_2^-, mg/L	0.01–0.52	0.11	0.15	0.01	0.15	0.01	0.01	0.20–0.22	0.28	0.01	0.003–0.01	0.01–0.08
NH_4^+, mg/L	1.45–1.88	0.21	0.31	<0.1	<0.1	0.54	0.12	0.49–0.56	<0.1	0.59	0.42–0.70	0.10–1.24
Si, mg/L	17.9–31.1	4.36	4.98	0.93	2.02	8.18	18.4	2.7–2.7	4.6	1.70	5.68–6.71	3.68–7.87
P_{tot}, mg/L	0.04–0.05	0.05	0.05	0.10	0.11	0.08	0.05	0.06–0.09	0.08	0.38	0.08–0.16	0.20–0.24
Σ_{ion}, mg/L	3026–6210	2839	5191	394	508	2249	9065	383–389	529	92	85.9–108	146–333
Al, mg/L	28.6–49.8	8.6	12.6	0.12	0.03	0.03	131	0.08–0.10	0.04	0.24	0.03–0.05	0.02
Mn, mg/L	66.2–184	50.4	155	0.05	0.02	0.07	296	0.64–0.68	0.23	0.03	0–0.01	0.01
Fe, mg/L	23.5–568	0.06	0.10	0.13	0.03	0.04	0.48	0.03–0.05	0.15	0.25	0.10–0.11	0.02
Co, mg/L	0.69–2.01	0.20	1.56	4×10^{-4}	2×10^{-4}	4×10^{-4}	4.03	5×10^{-4}	2×10^{-4}	1×10^{-4}	$2–3 \times 10^{-4}$	1×10^{-4}
Cu, mg/L	0.95–2.70	0.61	1.17	4×10^{-3}	3×10^{-3}	2×10^{-3}	8.35	1×10^{-3}	8×10^{-4}	0.01	$2–3 \times 10^{-3}$	1×10^{-3}
Zn, mg/L	266–810	294	830	0.10	0.04	0.05	1313	0–0.01	3×10^{-3}	0.01	0.01	3×10^{-3}
As, mg/L	0.01–1.45	2×10^{-3}	4×10^{-3}	0.05	0.06	0.01	0.01	0.01	0.01	0.01	$2–3 \times 10^{-3}$	0.68
Cd, mg/L	2.01–3.0	6.31	13.1	9×10^{-4}	6×10^{-4}	8×10^{-4}	38.9	$4–5 \times 10^{-4}$	3×10^{-4}	6×10^{-5}	5×10^{-5}–1×10^{-4}	$6–7 \times 10^{-5}$
Pb, mg/L	0.14–0.34	0.47	0.66	3×10^{-3}	2×10^{-3}	9×10^{-4}	1.70	8×10^{-4}	8×10^{-4}	1×10^{-3}	7×10^{-4}–2×10^{-3}	$4–5 \times 10^{-4}$
Sb, mg/L	0.78–1.02	0.95	2.49	3.14	1.96	1.94	1.71	0.10–0.17	0.26	0.29	0.81–1.66	4212–6982
WT	SO_4 Mg–Ca****	SO_4 Ca–Mg		HCO_3–SO_4 Ca–Mg	SO_4–HCO_3 Ca–Mg	SO_4 Mg–Ca	SO_4 Ca–Zn–Mg	SO_4–HCO_3 Na–Ca		HCO_3 Mg–Ca	SO_4–HCO_3 Mg–Ca	HCO_3–SO_4 Mg–Ca

Sampling points are shown in Fig. 1. * Parameters: S, area; T, water temperature; Eh, redox potential; PO, permanganate oxidizability; WT, chemical type of water; **, total length of the river (km); ***, min–max; ****, in the sample ShG-2, water type is SO_4 Zn–Mg–Ca.

actively migrate and accumulate in neutral and alkaline waters. Their concentrations reach very high values in the waters of two mining lakes of the Zhipkoshinsk deposit (Table 1).

The main distinguishing feature of the studied water bodies is a wide range of pH values in the aquatic environment, which determines the water types of different acidity (Chechel and Zamana, 2009). Acidic waters with abnormally high concentrations of heavy metals are formed due to the oxidation of sulfide minerals included in the composition of ores in the absence or insufficient contents of carbonate minerals in ores or host rocks to neutralize acidity. Otherwise, as was shown for other polymetallic deposits in the Eastern Transbaikal region, the waters have neutral or alkaline pH levels and significantly lower concentrations of heavy metals (Zamana and Chechel, 2015).

Phytoplankton

Representatives of the phytoplankton of the studied water bodies belongs to 75 taxa of a rank below the genus from eight divisions (Chlorophyta, 29 taxa; Bacillariophyta, 25 taxa; Cyanobacteria, 5 taxa; Chrysophyta, 4 taxa; Cryptophyta, Charophyta, Dinophyta, and Euglenophyta, 3 taxa each). The smallest number of taxa (2) was noted in the Sherlovaya Gora tailing dump, the largest (52), in the dammed lake near the settlement Sherlovaya Gora. No plankton algae were found in the Sherlovaya Gora ore quarry.

Phytoplankton was dominated by Chlorophyta (8–59%) and Bacillariophyta (14–50%). Green and diatom algae had the largest weight in the Sherlovaya Gora and Orlovsk tailing dumps, diatoms, in the Spokoininsk tailing dump and a dammed lake (Malaya Kulinda River). The dominant phytoplankton complex was chlorophyte-diatomic with participation of Chrysophyta and Cryptophyta. Chlorophyta (72–86% of the total abundance) prevailed in the dammed lake (Malaya Kulinda River) and the Spokoininsk tailing dump, while Bacillariophyta (15–61%), Chlorophyta (up to 20%), and Chrysophyta (14–29%), in the Orlovsk tailing dump. In the water bodies of the Sherlovaya Gora deposit, the dominant complex is diatom-chlorophyte with a noticeable participation of cryptophytes (up to 90% in ponds) and golden algae (up to 30% algae).

A biotopic analysis of the flora showed that planktonic (39%) and facultative planktonic (42%) algae were more diverse. According to phytogeographic analysis, most of the algae (73%) are widespread and common. Holarctic, arctoalpine, and boreal species from Chlorophyta and Chrysophyta indicate some specificity of the flora of the studied water bodies. In relation to mineralization, the algoflora is represented by freshwater species (88%) and euryhaline species (12%). Among the halophiles, *Nitzschia graciliformis* Lange-Bertalot & Simonsen 1978 and *Oocystis lacustris* Chodat 1897 were noted. The distribution of species with respect to pH is as follows: 61% are pH-tolerant species and 39% are alkaliphiles. Alkaliphiles include such a massive and frequently encountered species as *Fragilaria radians* (Kützing) D.M. Williams & Round 1987.

The abundance and biomass of algae varied over a wide range: from 1.84 (pond of the Sherlovaya Gora deposit) to 1627.68 thousand cells/L (Orlovsk tailing dump) and from 0.58 (Sherlovaya Gora tailing dump) to 1691.08 mg/m^3 (lake downstream the dumps of the ore quarry) (Table 2).

Quantitatively, phytoplankton is dominated by green and diatom algae that account for up to 90 and 85% of the total abundance and up to 70 and 92% of the total biomass, respectively. Seven species were widespread: *Dinobryon sertularia* Ehrenberg 1834 among Chrysophyceae, *Fragilaria crotonensis* Kitton 1869, *F. radians*, and *Lindavia comta* (Kützing) Nakov, Gullory, Julius, Theriot & Alverson 2015 among diatoms, *Cryptomonas erosa* Ehrenberg 1832 and *C. caudata* Massart 1920 among cryptophytes, and *Monoraphidium contortum* (Thuret) Komárková-Legnerová in Fott 1969 and *Schroederia setigera* (Schröder) Lemmermann 1898 among green algae. Species of the genus *Cryptomonas* (up to 80% in abundance and biomass) made the greatest contribution to the phytoplankton composition of the water bodies of the Sherlovaya Gora deposit. Diatoms (*F. crotonensis* and *F. radians* (48–62%)) and chrysophytes (*D. sertularia* (up to 30%)) dominated in the waters of the water bodies of the Orlovsk deposit. In the Spokoininsk tailing dump, the dominant species was *S. setigera* (80%).

Water bodies with acidic waters (pH ≤ 3) are an extreme habitat for hydrobionts (Seckbach et al., 2007). Our studies have shown the absence of algae in acidic conditions. The algoflora of German lakes acidified with ore drainage waters (Seckbach et al., 2007; Rönicke et al., 2010; Weithoff et al., 2010) consists of about ten species with the dominance of stenobiont nanoflagellates *Ochromonas* (Chrysophyta), *Chlamydomonas* (Chlorophyta), and *Gymnodinium* (Dynophyta). Phytoplankton of the water bodies we surveyed at pH in the range of 3–6, only 2–4 species of algae from the divisions Bacillariophyta, Cryptophyta, and Chlorophyta were noted. Our data confirm that the species richness of algae in nonaggressive and neutral slightly alkaline waters (pH 7–8.8) is significantly higher than in the water bodies with low pH (Lessmann et al., 2000; Wollmann et al., 2000; Nixdorf et al., 2001; Romanov et al., 2011; Kopyrina, 2016). In the water bodies of the Sherlovaya Gora and Orlovsk MPPs, the number of detected systematic groups in the composition of plankton algae varied from five to seven, and the number of taxa with a rank below the genus was the highest.

Table 2. Some indicators of phyto- and zooplankton in technogenic waters of mining objects of ore deposits in the Eastern Transbaikal region

Phytoplankton

	SG-5	SG-6	SG-8	SG-9	SG-10	SG-11	OR-3	OR-7	OR-8	MK-2
*n**	4	4	37	52	9	2	22	29	13	8
*N***	1.84	863.63	244.15	1502.55	141	1.93	236.25–356.81	1627.68	132.63	14.20
B***	1.21	109	133.76	1619.08	374.91	0.58	339.76–553.88	727.95	20.24	7.43

Zooplankton

	SG-8	SG-9	SG-10	OR-3	OR-7	OR-8	MK-2	ZH-2****
n	5	12	9	32	17	12	3	2
N	12.05	57.63	219.02	5.89–141.60	601.44	228.21	58.80	–
B	19.79	46.26	380.37	16.48–297.47	774.34	6156.6	1447.28	–

Sampling points are shown in Fig. 1. * *n*, number of species; ** *N*, abundance, thousand cells/L (for phytoplankton) and thousand ind./m^3 (for zooplankton); *** B, biomass, mg/m^3; ****, qualitative sample.

Macroalgae

Among filamentous algae, eight taxa from four divisions were detected (Chlorophyta (four species), Ochrophyta (two species), and Cyanobacteria and Charophyta (one species each)). Macroalgae in the water bodies formed one-, less often two-species aggregations. Filamentous algae were found in shallow areas, among aquatic vegetation (water bodies of the Sherlovaya Gora deposit), as well as in the form of tangled threads in metaphyton (quarries of the Zhipkoshinsk deposit). No filamentous algae were found in the Sherlovaya Gora ore quarry.

The found species of macroalgae were also widely found in natural water bodies of the Transbaikal region. For example, *Cladophora fracta* (O.F. Müller ex Vahl) Kützing 1843 develops mainly in water bodies with a well-formed aquatic ecosystem, while *Ulothrix tenerrima* (Kützing) Kützing 1843 tends towards disturbed areas or young water bodies. Representatives of the genus *Tribonema* are typical in water bodies and watercourses that contact with the soil (Kuklin, 2014).

Zooplankton

In total, 63 zooplankton taxa with a rank below the genus level were noted, among them are Rotifera (40 species and subspecies), Cladocera (13 species), and Copepoda (10 species). The total number of taxa varied from 2–3 (Zhipkoshinsk quarry and dammed lake, the Malaya Kulinda River) to 32 (Orlovsk tailing dump). Plankton invertebrates were not found in the ore quarry, tailing dump and ponds of the Sherlovaya Gora deposit.

Zoogeographically, the found zooplankton species are widely distributed (cosmopolites, 52%; Holarctic, 35%; and Palearctic, 15%). Such species as *Brachionus quadridentatus* Hermann, 1783, *Euchlanis dilatata* Ehrenberg, 1832, *Lecane luna* (Müller, 1776), *Cephalodella gibba* Ehrenberg, 1830, and *Trichocerca longiseta* (Schrank, 1802) inhabit all biogeographic zones; species *Mytilina mucronata* (Müller, 1773), *Kellicottia longispina* Kellicott, 1879, *Daphnia galeata* G.O. Sars, 1864, and *Alona guttata* G.O. Sars, 1862 are typical only in the Holarctic zone, while the copepods *Cyclops vicinus* Uljanin, 1875 and *Neutrodiaptomus incongruens* (Poppe, 1888), in the Palearctic.

According to biotopic confinement, in the studied water bodies eurybiont species (35%) are most abundant, while littoral and phytophilic species account for 24 and 22%, respectively. Planktonic species are represented by 16%, and benthic species, by 3%. Eurybiont species included *C. gibba*, *L. luna*, *E. dilatata*, *Brachionus angularis* Gosse, 1851, *Keratella quadrata* (Müller, 1786), *Chydorus sphaericus* (O.F. Müller, 1785), *Coronatella rectangula* (G.O. Sars, 1862), and *Eucyclops serrulatus* (Fischer, 1851). Species of the littoral-phytophilic fauna include rotifers of the genera *Euchlanis*, *Trichocerca*, *Mytilina*, *Notommata*, and *Testudinella* and crustaceans of the family Chydoridae.

The quantitative indicators of zooplankton varied significantly. The total abundance varied from 5.89 to 601.44 thousand ind./m^3; the total biomass, from 16.48 to 1447.28 mg/m^3. The central part of the Orlovsk tailing dump was characterized by a low density of aquatic organisms, while the highest density was observed in the water body downstream this tailing dump (Table 2).

The structure of the zooplankton community in water bodies also varied. In the Orlovsk tailing dump and in the pond (Malaya Kulinda River), Cyclopoida dominated at the stages of nauplii and copepodites. In the tailing dump, the share of copepods (*N. incongruens*, *E. serrulatus*, *C. vicinus*, and *Diacyclops bicuspidatus* (Claus, 1857)) in total accounted for 58–88% of the total abundance and 94–98% of the total zooplankton biomass. In the river dam, the main abundance and bio-

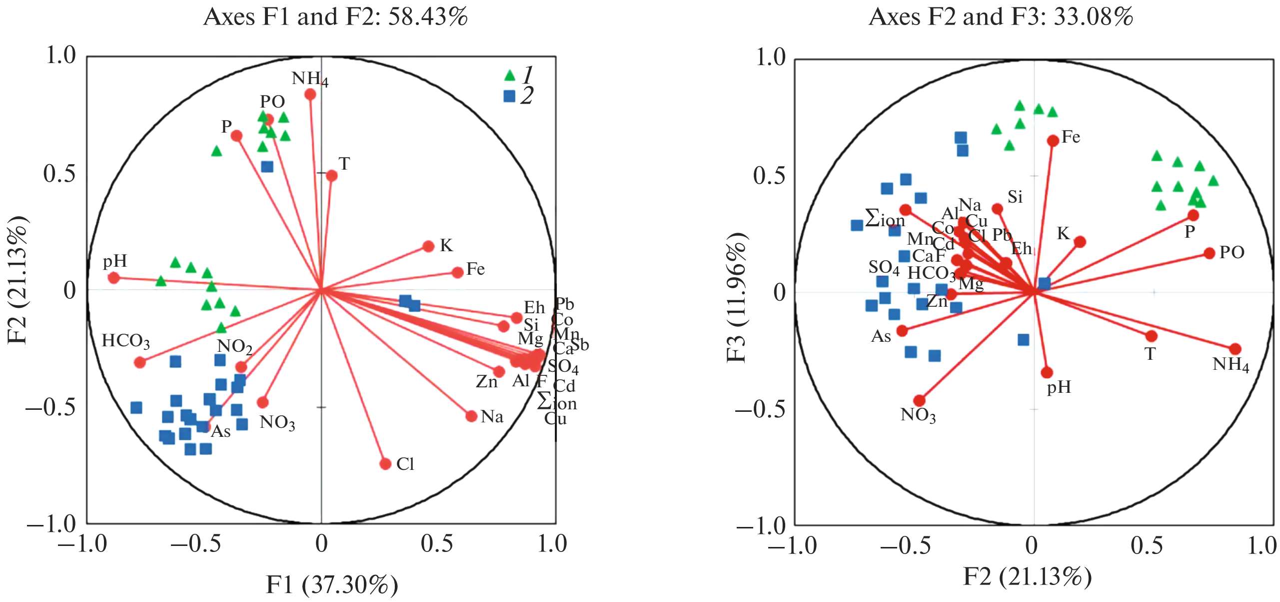

Fig. 2. The locations of physicochemical indicators and main characteristics of phyto- (2) and zooplankton (1) of technogenic waters of ore deposits in the space of three components. Symbols of abiotic parameters are presented in Table 1.

mass was presented by *Cyclops furcifer* Claus, 1857 (90 and 88%, respectively). In the Spokoininsk tailing dump, the main abundance and biomass was formed by Crustacea (*C. vicinus*, 53 and 13%, and *Daphnia curvirostris* Eylmann, 1887, 22 and 85%, respectively). The zooplankton community of the dammed lake (Sherlovaya Gora settlement) consists mainly of copepods (*E. serrulatus*, 38%) and rotifers (*Polyarthra longiremis* (Carlin, 1943), 35%, and *Keratella cochlearis* (Gosse, 1851), 17%). However, according to biomass, the prevailing phyla were Rotifera (69%) and Cladocera (20%). In the water body located downstream of the Orlovsk tailing dump, the most abundant were representatives of Rotifera (*B. angularis*, 76% and *K. quadrata*, 9%); however the main part of the zooplankton biomass was formed by Cyclopoida nauplii (49%). In the water bodies of the Sherlovaya Gora MPP (the mining lake and lake located under the dumps of the ore quarry), the most abundant zooplankton representatives were rotifers (*Hexarthra mira* (Hudson, 1871) (79%) in the mining lake, and *Pompholyx complanata* Gosse, 1851 (27%), *Keratella* sp. (18%), and *Notommata collaris* (Ehrenberg, 1832) (9%) in the downstream lake) and copepoda nauplii (12 and 45%, respectively). The plankton biomass was represented mainly by juvenile stages of Copepoda (51 and 81%, respectively).

In acidic and slightly acidic waters (pH 3–6) of the Sherlovaya Gora deposit, as well as in the Belovsk presettling basin (Romanov et al., 2011), invertebrates were not found. Only one species of rotifer, *Cephalodella* sp., was found in the Austrian lake at pH 5–6 (Moser and Weisse, 2011). In the United States and Germany acidic mining lakes (with pH 2.3–3.9) were inhabited by 5–11 species of zooplankton (Deneke, 2000; Wollmann et al., 2000). Studies have shown (Leppänen, 2018) that the ubiquist species *Ch. sphaericus* is characterized by increased stress resistance, is the most tolerant to mine waters, and can reach high densities in acidic waters. However, in our studies, this species, although it was found more often than other organisms, was not a structure-forming component of zooplankton communities (the share in abundance was no more than 2%). The common pH range for the presence of *Ch. sphaericus* in the water bodies, corresponded to 7.5–8.3. In weakly alkaline water bodies (pH 7.5–7.8) of the Sherlovaya Gora and Orlovsk MPPs, the species richness of aquatic organisms was higher compared to other studied water bodies. The species structure of the zooplankton of these water bodies has similar features with the technogenic water bodies of Transbaikal region (Afonina and Afonin, 2015, 2017; Afonina and Itigilova, 2012), Poland (Goździejewska et al., 2021), and Austria (Moser and Weisse, 2011), which is expressed in dominance of the juvenile stages of Cyclopoida and Rotifera.

Environmental Factors that Influence the Development of Phyto- and Zooplankton

To identify the leading factors that determine the change in the structural parameters of algae and plankton invertebrates, a factor analysis was carried out using the method of principal components. The analysis of variables made it possible to identify three main components that determine 70.39% of the variance of the actual data. The rest made an insignificant contribution to the total variance and were not included for further analysis (Fig. 2).

The first component (F1), which accounted for 37.30% of the total dispersion, was characterized by a positive relationship with the content of sulfates, magnesium, and calcium, as well as with Eh, the concentration of metals, and the sum of ions. It was also characterized by a negative relationship with pH and the concentration of bicarbonates. According to the analysis, positive factor loadings were determined by quantitative indicators of Cryptophyta, and negative factor loadings were determined by the number of species, abundance, and biomass of Cyanobacteria, Bacillariophyta, Chrysophyta, Charophyta, Chlorophyta, Euglenophyta, Dynophyta, and Rotifera. The second component (F2 = 21.13%) is characterized by a positive relationship with the content of organic matter (ammonium nitrogen, total phosphorus, and permanganate oxidizability) (in descending order of the factor load), determining the quantitative indicators of crustaceans. The third component (F3 = 11.96) is closely related to the Fe concentration, which affects the abundance of all zooplankton and rotifers.

According to the data we obtained, in technogenic water bodies, cryptophyte algae are the less tolerant to the increased content of trace elements. However, in natural lakes (Gabyshev and Gabysheva, 2020; Sharov, 2020), diatoms and green algae are less tolerant to the concentrations of chemical elements. Our results confirm (Kalin et al., 2001; Moser and Weisse 2011; Ferrari et al. 2015; Pociecha et al., 2018; Goździejewska et al., 2021) that the hydrochemical parameters (pH and high concentration of sulfates, hydrocarbonates, metals, and biogenic elements) can potentially influence the diversity and quantitative development of rotifers and crustaceans.

CONCLUSIONS

Technogenic water bodies of ore deposits in the South-Eastern Transbaikal region differ significantly in morphometric, physicochemical, and hydrobiological parameters. Distinctive features of water bodies are a wide range of pH values and the amount of water ions. According to the chemical composition, the waters are predominantly sulphate and bicarbonate-sulphate, with different ratios of magnesium and calcium. The hydrobiological part of this study made it possible to determine the species composition, quantitative indicators, and the complex of dominant species of algoflora and zooplankton. An analysis of the influence of environmental factors on the development of algae and plankton invertebrates showed that they are mostly affected by hydrochemical factors that determine the overall water mineralization, as well as micro- and macrocomponent composition, organic matter, and pH.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interests. The authors declare that they have no conflict of interest.

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